CHAPTER 1

Matter and Energy: An Atomic Perspective

OVERVIEW

The objective of this chapter is to introduce some of the basic concepts in chemistry using substances familiar to most students. After a historical introduction to chemistry, matter and energy are defined, and different forms and classes of each are discussed. Mixtures of matter and their separation are discussed, and the scientific method is outlined in the context of the development of atomic theory. The remainder of the chapter focuses on measurement and unit conversions.

For many students, the material in Chapter 1 is neither new nor particularly exciting. Some students are well versed in the topics in the chapter and may be bored by the repetition of this information. Others, however, are not as confident and need the foundation presented in Chapter 1. The challenge to an instructor is how to accommodate the needs of both groups.

We recognize that you, the instructor, may have your own favorite contexts within which to frame your classroom discussion of the traditional topics in Chapter 1. We hope you will use them. Additional contexts will challenge your students to see the similarities between those in the book and those presented in class. For example, one member of the author team uses a can of carbonated beverage to introduce the concepts of mass, volume, and density and the differences among the states of matter and among pure elements and heterogeneous and homogeneous mixtures. This context is one that every student can identify and understand.

Chapter 1 and the chapters that follow it include three features that we hope prove useful to you and your students:

- Each Sample Exercise is solved and paired with an unsolved Practice Exercise.
- Concept Tests are intended to compel the reader to pause and provide a nonnumeric answer.
    - As an instructor, you might use these questions as the basis for in-class discussion.
- Each Sample Exercise is solved using a set of steps:

  Collect and **O**rganize, **A**nalyze, **S**olve, and **T**hink about it (COAST).
    - COAST is by no means the only effective problem-solving methodology. You may have a time-tested method of your own. However, for the novice student, COAST provides one approach to problem solving. COAST is consistently applied in the solutions to *all* the Sample Exercises in this textbook and in the support package.

In this chapter, we have organized the material into nine learning outcomes:

1. Describe the scientific method.
2. Apply the COAST approach to solving problems.
3. Distinguish between the classes of matter and between the physical and chemical properties of pure substances.
4. Describe the states of matter and how their physical properties can be explained by the particulate nature of matter.
5. Distinguish between heat, work, potential energy, and kinetic energy, and describe the law of conservation of energy.
6. Use molecular formulas and molecular models to describe the elemental composition and three-dimensional arrangement of the atoms in molecules.
7. Distinguish between exact and uncertain values and express uncertain values with the appropriate number of significant figures.
8. Accurately convert values from one set of units to another.
9. Express the results of experiments in ways that accurately convey their uncertainty.

The additional activities have been classified according to these learning outcomes.

TEACHING THE CONTEXT

The opening chapter of a general chemistry textbook poses a challenge to a textbook author. Typically, the content is light on chemistry. Certain topics, such as measurement and unit conversions, are unlikely to evoke an enthusiastic response from students. One is often tempted to skip this material altogether in favor of "real chemistry" in subsequent chapters. Nevertheless, given the diversity in background of the students, these topics must be included and discussed. What we have tried to do in Chapter 1 is to combine standard introductory material with an interesting context.

Consistently throughout this book, we start with observations of the world around us. We see familiar objects around us, all of which are examples of **matter** (Section 1.1). **Chemistry** is the science of matter. As an instructor, you might focus on some simple examples of matter in the classroom—some copper wire, a bottle of water a student may have brought to class, or a piece of gold jewelry. Of what are these examples of matter composed? Matter has **mass** (an **extensive property**) and occupies space. All matter is composed of **atoms** (see Figures 1.1 and 1.5 as examples). Copper wire is an example of a **pure substance** and of an **element**, copper, which has certain **physical properties**, such as **density**, an **intensive property**. Most students should realize that copper can be pounded into thin sheets, can be drawn out into wire, and has high electrical conductivity. The tarnish sometimes observed on a wire is a **chemical property** of copper (its reactivity toward oxygen). One might even demonstrate another chemical reaction of copper by dropping a little copper wire into nitric acid. The text uses gold as an example of density determination (Figure 1.5). Is the gold jewelry you wear a pure substance? The answer is yes only if the gold is 24 karat. [One karat is equal to 1/24 (4.17%) of the weight of the metal in a mixture.] Drop a gold ring into nitric acid—nothing happens, showing the different chemical properties of copper and gold. You may need to cheat here and use a piece of cheap 14-karat gold jewelry rather than finding more expensive 22- or 24-karat gold. At this point it might be useful to reveal the periodic table of the elements and locate copper, gold, and the other elements.

Which element is water? This may be a silly question to nearly everyone in the audience, but it is one that is worth asking on the first day of class. A mixture of ice and water is a very useful visual aid or prop here. Water, of course, isn't an element at all but a pure substance that is a **compound** with a **chemical formula**: H_2O. Water is a **molecule** composed of the elements hydrogen and oxygen. Demonstrating that water is composed of two gaseous elements is easy if you have a simple electrolysis apparatus available. (Connecting a large dry cell to two pencils immersed in a beaker of water is sufficient to illustrate the generation of hydrogen and oxygen.) In the chapter, water is used to demonstrate the different phases of matter because it exists in three physical states that will be familiar to students: **gas**, **liquid**, and **solid** (Figure 1.10). Boiling water on a hot plate can provide a visual illustration of the concept of water vapor.

Why is it important to restrict our discussion to copper wire and 24-karat gold jewelry? Contemporary "copper" pennies are examples of **heterogeneous mixtures**: they have a zinc core surrounded by a copper cladding. A 14-karat earring is a **homogeneous** mixture of 58.3% Au and 41.7% Cu by mass. How would you separate the copper from the gold in 14-karat gold? Here is an opportunity to combine several observations. We have seen that nitric acid dissolves copper but not gold. Both metals and the homogeneous mixture of 14-karat gold (alloys are defined in Chapter 18) will dissolve in a mixture of HCl and HNO_3 (aqua regia, 3:1). In principle, electrolysis (as for water) will deposit copper at a lower potential than that required for gold. The same procedure is applicable to the separation of copper from zinc in a penny. Both metals dissolve in nitric acid yet are deposited electrochemically at different potentials. It is tempting to demonstrate the etching of the copper from the outside of a penny with acid to show the zinc core, but this would not be wise to be done outside of a fume hood. **Distillation** (Figure 1.6a) of the homogeneous mixture obtained by dissolving copper in nitric acid separates the water from the ionic compound copper nitrate based on **volatility**. If you restrict yourself to pennies, copper wire, and and gold jewelry, then **filtration** becomes a bit trickier to illustrate. One choice is to evaporate the copper nitrate solution until crystals (solid) form, followed by filtration. This can be done during the lecture as part of the distillation demonstration.

Copper wire and gold jewelry (assuming you did not sacrifice them to the acid treatment) provide the context for discussing measurement, **conversion factors**, the uncertainty inherent in all measurements, and the need to consider **significant figures** in both measurements and calculations involving experimental data (Sections 1.7 and 1.8). The density of either object can be calculated from measurements of the mass and volume. In making each measurement, the uncertainty depends in part on the **precision** and **accuracy** of each measurement (Figure 1.23). The calculation of density forces you to take into account the number of significant figures dictated by your measurements.

How do we know that all matter is composed of atoms? The answer to this question allows for the discussion of the differences among **hypotheses**, **scientific laws**, and **theories** and the role of the **scientific method** (Section 1.1).

Toward the end of the chapter, temperature is introduced as a commonly measured quantity (Section 1.7). This provides an opportunity to review the three commonly used temperature scales, **Celsius**, **Fahrenheit**, and **Kelvin**, and to discuss the conversion of temperatures between the three scales.

PARTICULATE REVIEW AND PREVIEW

Chemistry is a science that deals with substances that are very small and are impossible to see with the naked eye. One of the most important skills that must be developed by chemistry students is the ability to visualize atoms and molecules, as well as different phases of matter. In the Particulate Review section of this first chapter, the authors focus on developing these visualization skills and describe one way that atoms and molecules can be visualized. While this may be a review for students who have previously taken a chemistry course, this will be a novel concept for those who have not been exposed to chemistry. Students will undoubtedly be familiar with the different phases of matter, and the images in this review section demonstrate how one can visualize these phases at a particulate level.

The Particulate Preview then shifts the students' focus to how the constituent atoms and molecules can be represented. The images focus a student's attention on how different types of substances (compounds, elements, and ionic solids) can be represented. At this point in the course, the different atoms are distinguished by the colors of the spheres. Other ways of representing atoms and molecules are discussed in Section 1.6. These representations of molecules and atoms are a crucial foundation for the rest of the course and will be used throughout its entirety. While there are many excellent resources on how students develop visualization skills, these are more appropriate for later chapters, and we will return to these in Chapter 5.

ALTERNATIVE CONTEXTS
(Key Terms Bolded)

A Chemist's View of a Soda Can and Selected Foods

We suspect that some instructors struggle with the question of how to make the study of chemistry seem relevant to a class of science majors from a variety of disciplines, among whom chemistry majors are likely to be a minority or even absent. One answer is to provide the students with examples from the world around them. This is the basis for many of the science pages in magazines and newspapers as well as popular books written for the nonscientist.

Although we have chosen the making of metal tools and early metal work as the context for the introduction of the fundamentals of chemistry, one could choose from many alternative contexts. One example is to focus on a can of soda such as Coke or Pepsi. Advertisements for these products abound, and there is a high probability that a student in your class has brought a can of soda to the lecture. You might want to bring one yourself. A can of soda illustrates all three phases of matter: solid, liquid, and gas. The aluminum can (excluding the paint on the outside) is a **pure substance** and an example of an **element**. Aluminum is a **metal** (or **metalloid**) that in this case has been formed into a thin sheet; this is possible because of aluminum's malleability, an example of a **physical property**. How can we use a can of Coke to illustrate **chemical properties**? Ask the students to reflect on the fate of steel versus aluminum containers left out in the rain by the side of the road. Iron rusts, but aluminum does not (ignoring for the moment that aluminum will slowly oxidize to aluminum oxide).

The contents of the sealed can represent a **homogeneous mixture** containing the ingredients listed on the label. Once the can is opened, the unequal distribution of the gas bubbles makes it a **heterogeneous mixture**. The gas is carbon dioxide, a **molecular compound** containing two nonmetallic elements, carbon and oxygen, with the **molecular formula** CO_2. The sodium present in the soda is, of course, not in the elemental form but is found as the sodium **cation** with some unspecified **anion** to balance the charge.

How could we separate this mixture? **Distillation** would allow us to remove the highly volatile CO_2 and to separate the water from the other ingredients based on **volatility**, leaving behind a mixture of molecular and ionic compounds. One could make the argument that as the volume of the solution decreases, the precipitated solids can be removed by **filtration**.

A can of soda is typically labeled with its volume, 12 fl oz or 355 mL. This represents a fine introduction to the **units** used in measurement and serves as an example of unit conversions. Is 12 fl oz really 355 mL? Notice that the two values contain different numbers of **significant figures**. How does this affect a calculation that converts 12 fl oz to milliliters? Notice that the mass of the soda is not given. How could we determine the mass of the solution (assuming that the mass of the can itself is minimal)? By weighing the can of soda, we are forced to ask about the **accuracy** and **precision** of our measurement. Furthermore, with the mass of the soda in hand, we can calculate the **density** of the solution. (This discussion can also be related to the laboratory experiment by Herrick et al. that can be found in the "References" section below.) The concept of density could be broadened out to other food products as suggested by Robert Wolke. On pp. 191–194 of *What Einstein Kept Under His Hat*, Wolke responds to a question about bobbing for apples by determining which fruits float and which fruits sink in water. He then discusses other common foods, such as raviolis, that will sink at first and then float when they are cooked.

Finally, most of us would prefer to drink our soda cold rather than warm. What do we mean by *cold*? This clearly depends on which temperature scale we use: **Fahrenheit**, **Celsius**, or **Kelvin**. Whereas 0°C might be a nice temperature for a cold soda, 0°F would probably leave us with a slush, and 0 K represents an unattainable, **absolute zero**. Throughout this *Instructor's Resource Manual* we will return to the soda can and to food items as alternative contexts.

ACTIVE AND COLLABORATIVE

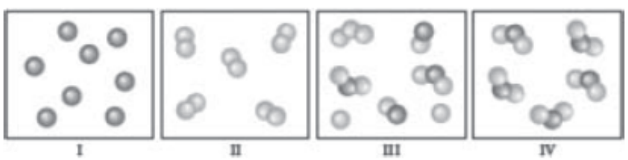
CLASSROOM EXERCISES

Clickers in Action

The following clicker questions, which reflect the concepts contained in the chapter, have been se-lected from Margaret R. Asirvatham, *Clickers in Ac-tion* (W. W. Norton). The listed chapter numbers cor-respond to the location of the question in the *Clickers in Action* text. An electronic version of these clicker questions is available at **wwnorton.com/ instructors** and these questions are organized according to the *Chemistry: An Atoms-Focused Approach*, 2nd Edition textbook.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 6)

Which of these atomic and/or molecular views represent pure substances?



a. I and III
b. II and IV
c. I, II, and IV
d. II, III, and IV

This question provides visual reinforcement of the differences among elements, compounds, pure substances, and mixtures.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOMES 3 AND 4)

Which of these are chemical properties of matter?

I) Corrosiveness
II) Density
III) Flammability
IV) Melting point

a. I and II
b. I and III
c. II and IV
d. III and IV

This question asks students to differentiate between physical and chemical properties of matter. (Note: Corrosiveness and flammability may need to be defined. At this point in the course, some students may not realize that when an item burns, it is reacting with oxygen.)

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 3)

Extensive properties of a pure substance depend on sample size, whereas intensive properties are characteristic of that substance. Which of these properties are intensive?

I) Color
II) Mass
III) Density

a. I and II
b. I and III
c. II and III
d. I, II and III

This question reviews the difference between intensive and extensive properties.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 8)

Identify the best match between the dimension or quantity and its correct SI base unit.

Dimension or Quantity	Unit
a. Mass	Gram
b. Length	Kilometer
c. Time	Minute
d. Temperature	Celsius
e. Amount of substance	Mole

This question asks students to determine the correct match between quantity and the SI units and is a review of Table 1.2.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 8)

Select the correct relationship between these metric units of length or distance.

a. 1 km = 100 m
b. 1 mm = 10 cm
c. 1 nm = 10^9 m
d. 10^6 µm = 1 m

This question focuses on the prefixes used with SI units.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 7)

In which of these measured values are the zeros not significant figures?

I) 0.0591 cm
II) 504 g
III) 2.70 m
IV) 5300 L

a. I and II
b. II and III
c. I and IV
d. I, III, and IV
e. II, III, and IV

This question asks students to remember the rules of significant figures regarding zeros. This question could also be used to ask which number has the most significant figures or which ones have three significant figures.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOMES 7 AND 8)

A metal sample is hammered into a rectangular sheet with an area of 31.2 ft^2 and an average thickness of 2.30×10^{-6} cm. If the mass of this sample is 0.4767 g, predict the identity of the metal. The density of the metal is shown in parentheses. (Useful information: 1 in = 2.54 cm.)

a. Aluminum (2.70 g/cm^3)
b. Copper (8.95 g/cm^3)
c. Gold (19.3 g/cm^3)
d. Zinc (7.15 g/cm^3)

This question asks students to determine the density of a piece of metal given its dimensions and mass. This problem is an excellent one for demonstrating how to handle conversions with a squared unit, which is a very confusing topic for some students.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 9)

The melting point of pure benzoic acid is 122°C. Data obtained by four students in a laboratory experiment are shown. Which student's data are precise but not accurate?

Student A	Student B	Student C	Student D
115°C	119°C	122°C	118°C
112°C	118°C	121°C	120°C
118°C	119°C	122°C	124°C
116°C	120°C	121°C	126°C

a. Student A
b. Student B
c. Student C
d. Student D

This question asks the students to determine the accuracy and precision of four sets of measurements. An instructor can easily change the question to inquire about other combinations of accurate and precise.

CLICKERS IN ACTION, CHAPTER 7 (LEARNING OUTCOME 8)

Neon has a boiling point of 27 K. Express this temperature in degrees Fahrenheit.

a. 352°F
b. 168°F
c. −246°F
d. −411°F

In general, clicker questions requiring calculations are more time consuming; however, students should be able to take an educated guess at the answer to this question. By limiting the time they have to answer the question, you can force them to practice estimation, or the Analyze step of the COAST method for solving problems.

Related Activities from *ChemConnections Activity Workbook*

The following activities can be found in the *ChemConnections Activity Workbook* by Sharon Anthony, Kevin L. Braun, and Heather Mernitz (W. W. Norton).

ACTIVITY 1: WHAT AM I EATING? (LEARNING OUTCOME 8)

- This activity provides an opportunity to work through a number of problems involving unit conversions between common units, many of which should be familiar to students.

ACTIVITY 2: HOW DO WE CONVERT BETWEEN THE UNITS USED IN ENVIRONMENTAL SCIENCE? (LEARNING OUTCOME 8)

- This activity provides an opportunity to work through a number of problems involving unit conversions between common units, many of which should be familiar to students.
- In Part II of this activity, the units of parts per million (ppm) and parts per billion (ppb) are introduced. The units are presented as a ratio of two values and could be appropriate for some students. For others, this may be too advanced for this point in the course and may be more appropriate at a later time.

ACTIVITY 4: HOW CAN WE SEPARATE PLASTICS FOR RECYCLING? [LABORATORY] (LEARNING OUTCOME 4)

- This hands-on activity allows students to see how physical properties can be used to separate different plastics. It also provides a nice opportunity to discuss density and explain why certain plastics will float, while others will not.

Related Activities from *Calculations in Chemistry, 2nd Edition*

The following activities can be found in *Calculations in Chemistry, 2nd Edition* by Donald J. Dahm and Eric A. Nelson (W. W. Norton). The first five chapters of this companion text contain many useful lessons related to the material in Chapter 1.

CHAPTER 1: NUMBERS IN SCIENTIFIC CALCULATIONS (LEARNING OUTCOME 7)

- These lessons focus on writing and performing calculations with numbers written in scientific notation.

CHAPTER 2: THE METRIC SYSTEM (LEARNING OUTCOMES 7 and 8)

- These lessons focus on the metric system and the units used in this system. The prefixes used to represent the different units and calculations with the units are also covered.

CHAPTER 3: ATOMS AND SIGNIFICANT FIGURES (LEARNING OUTCOME 7)

- Lessons 3.2 through 3.4 focus on how to determine the significant figures in a number and how to carry significant figures through calculations.
- Lesson 3.1 [The Atoms (Part 1)] can be skipped. This exercise might be more useful when covering Chapters 2 and 3 in the text.

CHAPTER 4: CONVERSION FACTORS (LEARNING OUTCOME 8)

- Lessons 4.1 through 4.5 focus on conversions between units. This could be a topic with which students will struggle throughout the course, but this introduction is excellent and comprehensive.

CHAPTER 5: WORD PROBLEMS (LEARNING OUTCOMES 2 AND 8)

- These lessons take the student through the steps required to solve word problems. This is an important skill in general chemistry, and the presentation is similar to the COAST framework for solving problems that is presented in Section 1.2 in the text.
    - In some of the examples, units such as grams and moles are used. One could potentially use these examples without defining the units further and treating the units simply as equalities, or one could skip these problems and choose from the other problems in the chapter.

CHAPTER 11: DIMENSIONS (LEARNING OUTCOME 8)

- These lessons take the student through the fundamental concept that quantities in chemistry have units. The lessons begin by defining the base units used in chemistry and then demonstrate how to use equalities to convert from one unit to another.

ChemTours

The following ChemTours are available at **digital.wwnorton.com/atoms2**.

SIGNIFICANT FIGURES (LEARNING OUTCOME 7)

Section 1.7

SCIENTIFIC NOTATION (LEARNING OUTCOME 7)

Section 1.7

TEMPERATURE CONVERSION (LEARNING OUTCOME 8)

Sections 1.7 and 1.8

DIMENSIONAL ANALYSIS (LEARNING OUTCOME 8)

Section 1.8

REFERENCES

Classroom Demonstrations

Franz, D. A. Densities and Miscibilities of Liquids and Liquid Mixtures. *J. Chem. Educ.* **1991,** *68,* 594.

Katz, D. A. Science Demonstrations, Experiments and Resources. *J. Chem. Educ.* **1991,** *68,* 235.

Murov, S. Liquid–Solid Density: Observations and Demonstrations. *J. Chem.* Educ. **2013,** *90,* 1484.

Shakhashiri, B. Z. Separating Liquids: Fractional Distillation. In *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; University of Wisconsin Press: Madison, 1989; Vol. 3, p 258.

Suder, R. Meter Sticks in the Demonstration of Error Measurements. *J. Chem. Educ.* **1989,** *66,* 437.

Summerlin, L. R.; Borgford, C. L.; Ealy, J. B. Colorful Mixture Separation. In *Chemical Demonstrations: A Sourcebook for Teachers*; American Chemical Society: Washington, DC, 1988; Vol. 2, p 17.

Summerlin, L. R.; Borgford, C. L.; Ealy, J. B. Ira Remsen's Investigation of Nitric Acid. In *Chemical Demonstrations: A Sourcebook for Teachers*; American Chemical Society: Washington, DC, 1988; Vol. 2, p 4.

Summerlin, L. R.; Borgford, C. L.; Ealy, J. B. The Mysterious Sunken Ice Cube. In *Chemical Demonstrations: A Sourcebook for Teachers*; American Chemical Society: Washington, DC, 1988; Vol. 2, p 15.

Summerlin, L. R.; Borgford, C. L.; Ealy, J. B. Sugar in a Can of Soft Drink: A Density Exercise. In *Chemical Demonstrations: A Sourcebook for Teachers*; American Chemical Society: Washington, DC, 1988; Vol. 2, p 126.

Laboratory Exercises

In the beginning weeks of the first semester of general chemistry, instructors often choose laboratory experiments that will get students accustomed to working in the laboratory and exposed to the glassware and techniques that will be used during the two-semester sequence. With an atoms-focused text, the first chapter focuses on different types of matter and their properties, the scientific method, experimental error and significant figures, and measurement of temperature and density. You must pick and choose which topic(s) to highlight in the first laboratory experiment of the semester, and this will depend on your particular outlook. Laboratory experiments used in conjunction with this chapter can focus on several topics: separation of mixtures of substances, density, temperature measurements, and experimental error (which involves a discussion of precision and accuracy).

One popular experiment used to introduce the scientific method is the "penny experiment," in which students determine the mass of pennies from various years. This experiment introduces students to the determination of mass in the laboratory and to graphing.

- Bularzik, J. The Penny Experiment Revisited: An Illustration of Significant Figures, Accuracy, Precision, and Data Analysis. *J. Chem. Educ.* **2007,** *84*, 1456.
- Mauldin, R. F. Introducing Scientific Reasoning with the Penny Lab. *J. Chem. Educ.* **1997,** *74*, 952.

Another interesting experiment that can be done involves determining the number of candies in a jar. In the activity designed by Ryan and Wink, students must not only estimate the number of candies but also use quantitative measures (number, mass, and volume) to assist in their determination. Students must develop proportions between quantities and create conversion factors for use in their analyses.

- Ryan, S.; Wink, D. J. JCE Classroom Activity #112: Guessing the Number of Candies in the Jar—Who Needs Guessing? *J. Chem. Educ.* **2012,** *89,* 1171.

The separation of substances in a mixture is also a popular experiment for the first week of lab. Some experiments have students separate components (such as iron filings, sand, salt, and water) by physical methods. Other experiments have students separate a solution into its components using chromatography. Many dramatic experiments involve separating the dyes used in coloring food. A number of these experiments incorporate high-performance liquid chromatography to separate or visible spectroscopy to quantify the amount of dyes, and you might not want to incorporate these techniques into your course at this point. One simple way to introduce separations is to use a miniature liquid chromatography column (such as a Sep-Pak cartridge) coupled with a syringe. This experimental setup is relatively inexpensive and can be used to separate the food dyes present in grape-flavored Kool-Aid.

- Bidlingmeyer, B. A.; Warren, F. V. An Inexpensive Experiment for the Introduction of High Performance Liquid Chromatography. *J. Chem. Educ.* **1984,** *61,* 716.
- A version of this experiment is also available from Vernier (vernier.com) in their *Advanced Chemistry with Vernier* lab manual.

There are many experiments involving density intended for the first weeks of general chemistry lab. At some institutions, students are asked to determine the identity of unknown metals by determining their densities. In many experiments, students use the density of water to look at the precision and accuracy of laboratory glassware. The experiments described in the two references given below ask students to use various pieces of laboratory glassware (such as burets, graduated cylinders, volumetric pipets, and beakers) to measure out a particular volume of water. The actual amount of water is determined by measuring the mass of the liquid and converting to volume using density.

- Jordan, D. Which Method Is Most Precise; Which Is Most Accurate? *J. Chem. Educ.* **2007,** *84*, 1459.
- Prilliman, S. G. An Inquiry-Based Density Laboratory for Teaching Experimental Error. *J. Chem. Educ.* **2012,** *89,* 1305.

A variation on this experiment has been proposed by Herrick et al. In this experiment, students determine the densities of Coke and Diet Coke and then pool their data to make conclusions about the accuracy and precision of various pieces of laboratory glassware.

- Herrick, R. S.; Nestor, L. P.; Benedetto, D. A. Using Data Pooling to Measure the Density of Sodas: An Introductory Discovery Experiment. J. Chem. Educ. 1999, 76, 1411.

Another variation of this experiment is one where students must determine the density of an egg by "floating" it in an aqueous saltwater solution. Once the egg just touches the surface of the solution, the egg has reached neutral buoyancy, and the densities of the egg and of the solution are equal. The density of the solution can be determined using a volumetric pipet or buret according to the procedures described in any of the three articles referenced above.

Kuntzleman has also developed an interesting activity that illustrates the concept of density. In his activity, students create a "dynamic density bottle" by layering isopropanol and a saltwater solution and adding in different plastic beads. Students can then observe how these plastic beads float in certain layers and relate this behavior to the density of the beads.

- Kuntzleman, T. S. The Dynamic Density Bottle: A Make-and-Take, Guided Inquiry Activity on Density. *J. Chem. Educ.* **2015,** *92,* 1503.

Along these lines, Mary Carroll has also developed an interesting forensics-focused experiment using flotation to determine the identity of different "crime scene" samples.

- Saccocio, L. A.; Carroll, M. K. Density Determination by Water Displacement and Flotation: An Introductory Experiment in Forensic Chemistry. *J. Chem. Educ.* **2006,** *83,* 1187.

In this first chapter, the frequently measured quantity of temperature is discussed. The different temperature scales and the relationships between them are presented. The experiment described by Padgett and MacGowan has students explore the thermal expansion of various liquids as a function of temperature. Students must then graph the resulting data, which allows them to see which liquid is most sensitive to temperature changes.

- Padgett, L. W.; MacGowan, C. E. Thermometry as a Teaching Tool for Graphing: A First-Day Introductory Chemistry Laboratory Experiment. *J. Chem. Educ.* **2013,** *90,* 910.